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Substitutability Between Internal and External R&D and the Paradox of Openness

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Substitutability between internal and external R&D and the paradox of openness

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Abstract:

We explore how substitutability between internal and external R&D influences business conduct with regard to R&D approaches and their implementation with the support of managerial resources in a competitive innovation game. We develop a duopoly model which incorporates the assumption of substitutability due to managerial diseconomies of scope in firms using different innovation mechanisms to access technology.

We establish that firms substitute internal sources of innovation for external sources as exogenous spillovers increase to manage the diseconomies of scope. We find a tension between the knowledge disclosures and the protections of innovation returns that arises as a paradox for firms. The finding of a positive association between the choice of a firm to be connected with the R&D environment and the appropriability of its innovation returns is understood to be consistent with empirical results of a paradox of openness that firms open to external sources of innovation face.

Keywords: Substitutability in R&D; Internal and external R&D; Diseconomies of scope; Managerial attention; Absorptive capacity; Openness.

JEL Classification:

D43, L13, L25, O30

1. Introduction

Substitutability is one case of how internal and external R&D strategies interact in the generation of innovation. Substitutability between two innovation activities means that the marginal return to one activity decreases as the intensity of the other increases (Cassiman & Veugelers, 2006; Milgrom & Roberts, 1990, 1995; Topkis, 1998). Two sources of substitutability between internal and external R&D are switching costs (Rothaermel & Hess, 2007) and diseconomies of scope (Hess & Rothaermel, 2011). Substitutability in innovation can be caused by switching costs between different innovation modes (internal R&D, external knowledge sources) and diseconomies of scope associated with using different innovation mechanisms to access technology in tandem. The transaction costs literature tends to view the alternative scenarios of internal knowledge generation and external knowledge sourcing for innovation as substitutes (Williamson, 1985; Pisano, 1990). This is because of its emphasis on the relative costs of conducting innovation activities in-house or externally. Such relative costs determine whether it is efficient for firms to develop innovation internally or search for knowledge externally.

A considerable number of empirical studies found hard evidence of a substitution effect between internal R&D and external technology sourcing activities. The two innovation strategies for sourcing external knowledge are technology acquisition on the market and cooperation in R&D. Serrano-Bedia, López-Fernández and Garciá-Piqueres (2018) provide a review of the empirical studies on the nature of the relationship between different innovation knowledge sources, i.e., complementary or substitute relationships between available knowledge sources for a firm (internal, contractual arrangements in the market, and cooperation). The authors find numerous studies providing rigorous evidence on the substitutive relationship between internal and external knowledge sources. Given the accumulation of empirical evidence in favour of the substitutability hypothesis between

internal and external knowledge sources, it is surprising that little attention has been devoted to its theoretical and public policy implications.

Laursen and Salter (2006) presented some empirical evidence in favour of the hypothesis that searching for knowledge that firms access internally and externally are substitute activities, and subsequent work has produced considerably more. The importance of substitutability in R&D strategy is confirmed by Tsai and Wang (2009), and Berchicci (2013). The common features of these three papers are that a firmôs innovation performance is derived from using internal and external sources with firms tapping into external sources of knowledge through R&D contracting, and the substitutability between internal and external sources is measured through product innovation. Other papers studying the existence of substitutability on innovation performance between some innovation knowledge sources (internal, external (contracted R&D), and/or cooperation) employing different measures of innovation performance present evidence that suggest that this is indeed the case. The results from the studies by Beneito (2006) and Hagedoorn and Wang (2012) confirm previous evidence for substitutability between internal and external sources of knowledge for incremental product innovations (utility models) and for product and process innovations (patents), respectively. Love and Roper (1999, 2001), Jirjahn and Kraft (2012), and Guisado González, Guisado Tato, and Ferro Soto (2014) find evidence of substitutability in product innovation performance when firms combine in their R&D strategies internal and cooperation innovation knowledge sources.

The empirical literature on the nature of interaction between internal and external knowledge sources in innovation development is inconclusive, producing mixed results (Ennen & Richter, 2010; Hagedoorn & Wang, 2012). Thus, while some studies provide support for the complementarity hypothesis between internal development and external knowledge sourcing, other studies suggest the existence of a substitutability relationship between them. Still other studies found no conclusive empirical evidence on internal and external R&D activities and

their effects on innovation performance for product innovations (Schmiedeberg, 2008) and for process innovations (Vega-Jurado, Gutiérrez-Gracia, & Fernández-de-Lucio, 2009; Krzeminska & Eckert, 2016). The idea that firms benefit from complementing internal with external knowledge sources is well accepted in the literature (e.g., Arora & Gambardella, 1990; Cassiman & Veugelers, 2006), but most studies on complementarity of R&D activities focus on product innovations rather than process innovations (Krzeminska & Eckert, 2016). New empirical evidence suggests the likely existence of a contingent relationship between internal and external knowledge sources in shaping a firmôs innovative output instead of a clear-cut answer to the question of whether different innovation knowledge sources are complementary or substitute factors (Serrano-Bedia, López-Fernández, & Garciá-Piqueres, 2018).

Several organizational literature studies argued that organizational attention is a valuable and scarce resource in organizations (Simon, 1957; Cyert & March, 1963; March & Simon, 1993). Organizational scholars noticed the importance of attention as a scarce resource for determining firm behaviour. Managers deal with one or a few problems or aspects of reality at a time, because the limits on attention simply don't allow everything to be taken into account at once (Simon, 1947). The limited span of attention of any individual manager limits the ability of a firm to pursue many external linkages for innovation (Love, Roper, & Vahter, 2013). Firm behaviour, including decision making and strategy formation, is the result of how firms channel and distribute the attention of their decision-makers (Ocasio, 1997, 2011). Attentional perspective or focus on a limited number of issues and answers is a critical determinant of strategic action and adaptation. Firm innovation from a managerial perspective can be regarded as a constrained optimization problem (Rothaermel & Hess, 2007). In high-technology industries, firms face essentially limited managerial resources. This problem is particularly important when different innovation mechanisms can be substitutes for one another. Their simultaneous use by a firm might imply a decrease of its innovative output at the margin. It is

sufficient for a substitutive relationship to take place that using one innovation activity marginally decreases the benefit from using another (Hess & Rothaermel, 2011). The reason for this argument stems from the potential diseconomies of scope associated with using different mechanisms to access knowledge and innovate. Diseconomies of scope can be motivated by managerial constraints (Belleflamme & Peitz, 2015).

Firms cannot realize the benefits from external knowledge merely by being exposed to it (Cohen & Levinthal, 1989, 1990). Instead, they must develop ñabsorptive capacityò. R&D is important to build absorptive capacity since the ability to identify, assimilate and exploit new external knowledge is as function of own R&D. Intensity of R&D effort is crucial to put an effective absorptive capacity in place. It has been increasingly recognized the role of external linkages in building absorptive capacity (Lim, 2009). Establishing absorptive capacity through connectedness to external sources of knowledge can help a firm to access and acquire knowledge from those sources. A firmôs effort to build absorptive capacity involves not only R&D expenditures, but also how it manages its internal R&D together with efforts to link internal and external R&D. Organizational attention allocated to searching any particular source of existing ideas and information plays an enabling role by allowing the organization to build its absorptive capacity for innovation (Koput, 1997). If the attention allocated to an inside or outside source of ideas is very low, the organization may not be able to develop absorptive capacity by not having accumulated sufficient information. Absorptive capacity can be framed as an attention directing and action-generating capability which applies to knowledge residing within or across firms (Kim, Kim, & Foss, 2016). Innovation becomes possible when the firm allocates attention to the recognition, assimilation, and exploitation of new knowledge held externally or internally to the firm.

ñOpen innovationò, a term introduced in 2003 by Henry Chesbrough, involves the ñuse of purposively inflows and outflows of knowledge to accelerate internal innovation and expand

the market for external use of innovation, respectivelyò (Chesbrough, 2006). A firmôs choice to be open to the external environment is related to its appropriability strategy, i.e., its approach to capturing rents due to R&D. A major problem associated with assessing and using external sources of knowledge has to do with the fact that, in order to obtain knowledge, the firm has to disclose some parts of its own knowledge to external actors (Laursen & Salter, 2014). This introduces what the authors describe as the paradox of openness, where managers make their firm open by relying on external sources in order to innovate, but also have to protect their own firmôs knowledge from being copied and appropriate the benefits derived from their firmôs innovation.

Arora, Athreye and Huang (2016) argue that both patenting (appropriability) and external sourcing (openness) are jointly-determined strategic choices made by firms. Until then the existing empirical literature has treated the trade-off between appropriability and openness as a causal relationship. Openness, or external sourcing, and the paradox that it creates, entails a trade-off when opening up to outside sources of knowledge to create innovations may weaken the firmôs power to capture rents from that knowledge. Associated with this paradox, there are two conflicting views in the literature, which are called the ñspillover preventionò theory and the ñorganizational opennessò theory. Arora et al. (2016) expect to see a positive association between patenting and openness in the first view, and an inverse relationship in the second one. The relationship between appropriability and open innovation is an unresolved question (West, 2006). On the one hand, stronger intellectual property regimes are directly associated with more open innovation. A high degree of patent protection makes patents more attractive for technology licensing purposes and promotes vertical specialization (Gallini, 2002). On the other hand, the case of open source software raises questions about this relationship. Open source software is an increasingly popular example of open innovation. The free and open source movements contain intellectual property restrictions intended to force sharing of

software and value free access to source code (West & Dedrick, 2005). Firms involved in open source software often make investments that will be shared with real and potential rivals (West & Gallagher, 2006).

In order to explore this paradox of openness, several empirical investigations were conducted. Some studies find a positive relationship between appropriability and openness. Based on empirical analysis of data from 2005 UK Innovation Survey, Laursen and Salter (2014) explore how firmsô degree of openness for innovation is related to the strength of their appropriability strategy. The measure of the overall strength of the firmôs appropriability strategy combines responses on the degree of importance to the firm of different methods of protection. It includes formal methods, such as patents, registration of design, trademark, as well as informal methods, such as secrecy, lead time and product complexity. The aspects of firm openness examined are the breadth of the firmôs search efforts, and the range of types of partner organizations in formal collaborations for innovation. The authors find that overall appropriability strategy has a concave relationship with external search breadth and innovation collaboration breadth. That is, there is a concavity association (at least in terms of decreasing positive marginal effects) between appropriability and openness in the entire appropriability strategy scale. Their models confirm the predominantly positive relationship between strength of the appropriability strategy on the one hand, and breadth of external search and collaboration on the other.

Using data drawn from the 2003 Innovation in Australian Business Survey, Huang, Rice, Galvin and Martin (2014) investigate how openness actually affects a firmôs management of appropriability regimes to recoup benefits from its innovation. The authors find that the degree of openness is curvilinearly related to the scope of appropriability regimes. Firms with a higher degree of openness tend to employ a larger range of appropriability regimes. While firms that are more open may use an increasing range of appropriability regimes, there comes a point where the degree of openness has a declining marginal effect on the dependent variable. The

degree of openness is measured by the breadth of external knowledge sources and the scope of inter-organizational collaborations that a firm is involved with, and the measure of the scope of appropriability regimes combines both formal and informal methods of intellectual property protection. Formal methods include patent, and copyright or trademark, and informal methods include secrecy, and complexity of product design.

Arora et al. (2016) use data from the 2012 Survey of Innovation and Patent Use and the 2009 UK Community Innovation Survey to assess the link between patenting and openness (external sourcing). The openness is defined by the number of different types of the firmsô external collaborators. Firms cooperate in innovative activities with organizations such as suppliers of equipment, clients or customers, competitors, and universities and other higher education institutions. The results show a positive association between patenting and openness. The relationship between patenting and collaboration in innovation is stronger for technology leaders than for follower. The authors treat both patenting and external sourcing (openness) as jointly-determined decisions made by firms. The increase in patenting due to openness is higher for leading firms than for followers. Zobel, Balsmeier and Chesbrough (2016) analyse how the patent stock of new entrants in industries shaped by systemic innovation influences their subsequent openness in innovation. Openness in innovation is measured by the number of inter-organizational relationships that a firm enters in a given year. The results suggest that patents have a strongly positive effect on technology-intensive relationships that focus on joint scientific research, while relationships that are of decreasing technology intensity are gradually less affected by the new entrantôs patent stock.

The main objective of this paper is to explore how substitutability between internal and external R&D influences the business conduct of innovative firms with regard to R&D approaches and their implementation with the support of managerial resources in a competitive innovation game. We seek to shed some light on the unresolved question of if and how appropriability and

open innovation are associated with each other. The empirical justification for the notion of sourcing knowledge internally and externally as substitute mechanisms to advance innovation is provided by the evidence reviewed above. To this purpose, we develop a duopoly model which incorporates the assumption of substitutability arising between internal and external R&D due to managerial diseconomies of scope in firms using different innovation mechanisms to access technology, and with that we extend the previous analysis on strategic R&D investments with exogenous spillovers and endogenous absorptive capacity. To our knowledge, this study is among the first to investigate this topic in a game-theoretic setting. Due to the assumption that sourcing knowledge internally and externally are substitute mechanisms, the results of our model are qualitatively different from those of earlier models of R&D with exogenous spillovers or endogenous absorptive capacity determined by R&D approaches. Empirical evidence exists that provides support for our theory.

The main conclusions we reach are the following. We establish that firms substitute internal sources of innovation for external sources as exogenous spillovers increase to manage the diseconomies of scope associated with sourcing for knowledge both internally and externally. We focus on the generality of R&D performed by a firm as a way to take knowledge from external sources. We find a tension between the knowledge disclosures resulted from the R&D generality of a firmôs research approach and the protections of innovation returns facilitated by the R&D specificity of its research approach that arises as a paradox for firms. The finding of a positive association between the choice of a firm to be connected with the R&D environment and the appropriability of its innovation returns is understood to be consistent with empirical results of a paradox of openness that firms open to external sources of innovation face.

The remaining of the paper is organized as follows. In the next section, the game-theoretical model of R&D is briefly presented and analysed. In section 3, the comparative-statics implications of the competitive innovation game are established. In section 4, the results

concerning firmsô R&D approach behaviour under R&D competition are discussed. Finally, section 5 concludes the paper. A detailed description of the model, its formal analysis and proof are contained in the Appendix.

2. Model

In this section, we present a description of the model which is centred on the formulation of the effective R&D level. The detailed representation of the remaining part of the model as well as the derivation of its equilibrium results are provided in the Appendix.

A simple duopoly model can be set up to highlight the role of substitutability between the innovation mechanisms of sourcing new knowledge internally and externally. Firms act independently at each stage of the game. Firms first simultaneously choose research orientations and allocate scarce managerial resources to search for new knowledge internally and externally. Each of two firms has to make two decisions in stage 1. The remaining of the timeline of the duopoly game is that firms choose second their R&D output levels, and finally their Cournot outputs. The intuition behind this timeline is that the choice of a R&D approach and the allocation of managerial resources to different mechanisms of technology sourcing involve a longer term commitment than choosing an R&D output level.

Managerial attention plays an important role in identifying important ideas for innovation and absorption. The quantity of relevant ideas to be implemented in the production site of a firm is a function of the amount of attention allocated to search activities and the number of new ideas discovered by all firms. The amount of attention allocated to internal and external sources of knowledge is required to implement the firm chosen R&D orientation. Firms use different R&D strategies, choosing between innovate and imitate. Firms can improve their market profitability by making R&D investments that reduce the unit-costs of production. We posit that the effective level of unit-cost reduction of firm i is given as

ώ؛ سي ü ⍰è ρℏ ì؛؛ ώ؛ ط ü ⍰è⍁ ؛ ح ℏ ì؛ح⍁ ώحℏ ⍰ سي ρℏ ς, ⍰ ش ⍰ . (1)

The effective cost reduction of firm ⍰ depends not only on its own knowledge produced, ώ؛, but also on the other firmôs knowledge generated, ώح, via intermediate or final spillovers respectively, ⍰ℏ⍰ سي ρℏ ς and ⍰ ش ⍰. R&D activities are associated with positive spillovers. A firmôs R&D output leaks out to its rival at an exogenous rate π جى ؛ جى ρ, but shared R&D output is only partly assimilated and absorbed by the rival firm. Decision-makers of firm ⍰ allocate the amount ì؛؛ of its scarce managerial resource to look for innovative ideas within the organization, and the amount ì؛ح to look to see what others are doing. In the firmôs effective R&D activity, ì؛؛ώ؛ refers to the cost reduction obtained by innovation efforts ì؛؛ provided that ρ حي ì؛؛. The marginal productivity of firm ⍰ôs managerial effort to imitate ì؛ح is assumed to be constant too, either positive or zero. Beath, Poyago-Theotoky and Ulph (1998) introduce a two-stage process whose first R&D output is knowledge produced and final R&D is lower unit costs. Corresponding to the first stage is a process of search and discovery, and corresponding to the second stage is a process of combining pieces of knowledge into a specific form. Knowledge serves as an input that determines the amount of R&D output at the second stage.

The benefits arising from the utilization of external knowledge reflect the absorption efforts that make possible the imitation of the rivalôs ideas and are conditional upon the connectedness with the R&D environment pursued by firms. The absorptive capacity of a firm is dependent upon the firmsô choices of R&D approaches π جى ؛ ؛ جى ρ and π جى ؛ ح جى ρ by firms ⍰ and ⍰, respectively. Building this form of absorptive capacity involves a significant amount of managerial attention. The degree of firmsô connectedness pursued makes cognitive resources and absorption costs critical to the imitation of a fraction of external knowledge. We define the degree of connectedness between firms as the product of firmsô R&D designs, ؛ ؛ ح, which is consistent with the way firmsô connectedness is characterized by Wiethaus (2005). Higher values for ì؛ح are likely to bring about an increase in the effective degree of connectedness

ὒ ἶἐ ἶ ἶ ἶ ἱ ὶ صرجث. Clearly, the consistency requirements π جى ὒ ἶἐ ὃ ἱ ὶ ἱ ὒ ἶἐ ὃ ἱ ὶ صرجث جى ρ imposed on the extent to which knowledge generated is transformed through managerial efforts into unit cost reduction are satisfied.

Firms face a finite capacity to allocate attention of decision-makers to search activities. We suppose that the supply of managerial resources to a firm is fixed at a given amount. We assume that the tightly-constrained resource endowment of firm ἶ is equal to 1:

ὶ طى ὶ جى ρ, ἶ سي ρ ἱ ς, ἶ شى ἶ . (2)

Managersô limited attentional and cognitive capabilities may limit the ability of a firm to search for and learn from knowledge sources. We set the number of units of managerial time and effort available to the firm equal to one, which is the minimum strictly necessary to ensure that the firm has sufficient resources to fully use one innovation mechanism, either internal or external knowledge sourcing. A firm is likely to endure production disadvantages when conducting R&D to produce innovation and imitation. These disadvantages could result from the joint use of managerial inputs. In that case, its R&D production process involves diseconomies of scope. The cognitive and informational constraints imposed on firm management are exacerbated as firms increase the scope of their innovation activities. Scope diseconomies can offer each firm a difficult choice. In the extreme, each firm may have to choose between different innovation mechanisms representative of activities firms use to access knowledge in a discriminating fashion.

Next, we briefly describe the first-stage solution of the model. The solution strategy for determining ἷ ,ἷ , ὶ , ὶ , ὶ and ὶ , will be useful to eliminate variables to obtain ώ as a function of variables ἷ ,ἷ (and ώ , ώ) alone.

2.1 First-stage solution

We concentrate on the first stage of the game. Firms choose r_i, r_j, I_{ij} and I_{ji} first. They make these choices by relying on the fact that both firms are rational and strategic. Surely, rational behaviour implies that any resource allocation choice $\{I_{ij}, I_{ji}, \pi_i \geq \pi_i^{min}, \pi_j \geq \pi_j^{min}\}$ from (2). Reducing managerial resource losses is essential to achieve the full profit potential. Firm i will make its choices taking into account its best guess as to firm j's best-replies to the choices of r_j and I_{ij}.

The equilibrium values of the model are found in a backward fashion. After deriving firms' reduced-form profit functions $\pi_i = \pi_i(r_i, r_j, I_{ij}, I_{ji}, \omega_i, \omega_j)$ and best-responses ω_i to choices r_i, r_j, I_{ij} and I_{ji} in stage 2, $\pi_i \geq \pi_i^{min}$, $\pi_j \geq \pi_j^{min}$, firms choose those r_i, r_j, I_{ij} and I_{ji} options which turn out to maximize their profits. The stage 1 equilibrium amount of firm j's managerial attention allocated to external sources of knowledge is $I_{ij} = 1 - r_j$. We can find firms' optimal allocations of managerial resources given their optimal values of research approaches (and vice versa). Assume that r_i is the optimal level of firm j's research approach (and that r_j and I_{ji} are optimal values from the perspective of firm i). We can prove that $I_{ij} = 1 - r_j$ in equilibrium by the method of contradiction. Suppose that $I_{ij} < 1 - r_j$. Clearly, choosing $I_{ij} = 1 - r_j$ is not optimal from firm j's standpoint for a small decrease in I_{ij} such that $I_{ij} - \Delta I_{ij} = 1 - r_j$ will increase the coefficient of ω_i in $\ddot{\omega}_i$ as $I_{ij} = \rho$ and firm j's individual profit. Any small change in I_{ij} would leave the coefficients of ω_j and ω_i in $\ddot{\omega}_j$ unchanged. Choosing $I_{ij} > 1 - r_j$ will decrease the coefficient of ω_j in $\ddot{\omega}_i$. But then firm i could increase its profit by decreasing the coefficient of ω_i in $\ddot{\omega}_j$ without changing the coefficients in $\ddot{\omega}_i$ through a small decrease in r_i. So, the initial value of r_i would not be part of the optimal solution to firm j's profit maximization problem. The assumption that $I_{ij} < 1 - r_j$ is false must be wrong, so $I_{ij} = 1 - r_j$ must be true.

The direct gains (i.e., knowledge assimilation or cost reductions) from accessing outside sources of R&D are not costless. Firms may be adversely affected when conducting in-house R&D activities or bear costs in terms of loss of in-house R&D performance whenever they select broader (more similar) research approaches to keep them closer connected with their R&D environment. To put it another way, the efficiency coefficient of internal R&D output ὺ⃝è ρ‴ìὶ is ρطˆὶ ج حى ρ only if ˆ ὶ حي π. Instead, ρππÞ productivity of internal R&D is possible if firm ⃝ adopts the firm-specific R&D orientation ˆ ὶ سي π, which is then completely implemented with the support of managerial resources. Firm ⃝ has to take all available managerial resources and achieve maximum innovative results with them. It is worth noting that models of absorptive capacity in terms of research approaches traditionally assume that the choice of research design is purely strategic, so there are no-cost reasons for choosing one line of research to pursue rather than another (Katsoulacos & Ulph, 1998; Kamien & Zang, 2000; Wiethaus 2005). On the directions for further research, Kamien and Zang (2000) suggest that it would be more realistic to suppose that R&D costs depend on the R&D approach chosen though.

Thus, ὼὶ سي ىρ طي ìὶجىὼὶ طى ìὶ‴ ὼج from expressions (1) and (2) alongside the stage 1 equilibrium considerations above or, substituting ˆ ὶ ج in this equation for the effective level of cost reduction, we get

ὼὶ سي ىρ طيˆ ὶ ج ىὼὶ طى‴ ˆ ὶ ج ὼج‴ ⃝ سي ρ‴ ς, ⃝ ش ⃝ . (3)

Firm ⃝ôs non-cooperative optimal choice of R&D approach for a given ˆ ج in stage 1 can be determined as solution to the problem of maximizing “ὶىὶ ὶ‴ˆ ج‴ὼὶ‴ὼجى with respect to ˆ ὶ. The first-order conditions for each firm can be combined to form a system of two equations and two unknowns, the optimal research approach levels ˆ ὶ and ˆ ج. The profit maximization problem of firm ⃝ specified by defining each firmôs effective R&D level as in (3) is equivalent to the original problem of firm ⃝ specified in terms of representation (1) and resource constraint

(2). Therefore, optimizing the individual profit of firm ⁉ only over ↰ ᵢ is equivalent to the original problem where firm ⁉ optimizes over ↰ ᵢ and ℓ ᵢⱼ simultaneously. The relation between the optimal solution of the original problem and the solution of its equivalent problem is clear as ℓ ᵢⱼ ≔ ↰ ᵢ ∕ ↰ ⱼ.

The first stage of the game can be subsumed under a new first stage in which firms choose R&D approaches ↰ ᵢ and ↰ ⱼ. Any equilibrium level of managerial resource to look for new ideas outside a firm, ℓ ᵢⱼ, can be recovered by setting ℓ ᵢⱼ ≔ ↰ ᵢ ∕ ↰ ⱼ. It thus appears appropriate to henceforth posit the representation of firm ⁉ôs effective R&D in (3). We propose a truncated three-stage game with the same timeline and strategic choice variables as in Kamien and Zang (2000), and Wiethaus (2005). In the gameôs first stage, the two firms choose simultaneously their research approaches and in the second stage their levels of R&D output. Firms sell homogenous products to the final consumer in the third stage of the game, and the output level of each duopolist is chosen non-cooperatively. Kamien and ZangËs, Wiethausó, and our duopoly model set-ups differ in the firmôs effective level of cost reduction.

In representation (3) there is a dilemma of searching for new knowledge internally or externally that each firm ⁉ faces in its choice of R&D approach ↰ ᵢ. For absorption of external R&D one needs the generality of firmsô R&D approaches, while for exploitation of internal innovative possibilities the specificity of firmsô R&D approaches is more important. The economic dilemmas facing firmsô managers when there is a choice among multiple R&D approaches as illustrated in (3) can be grounded on one motive for substitutability between different mechanisms to innovation, that is, tight cognitive resource constraints and diseconomies of scope associated with using different innovation mechanisms in combination.

To account for representation (3) and the underlying substitutability between internal and external R&D, we focus on the case where there are diseconomies of scope which are managerial in nature, and possibly large ones. The simultaneous use by a firm of different

mechanisms to access knowledge implies a decrease of its innovative output and effective cost reduction as follows. If either$\theta_i \neq \pi$ or$\theta_j \neq \pi$, firm ïôs effective R&D activity turns into own R&D: $\ddot{\omega}_i \neq \dot{\omega}_i$. When compared with the case of joint production of innovation and absorption, a firm specializing in innovation generates more unit-cost reduction from given $\dot{\omega}_i$, and so more R&D output level $\dot{\omega}_i$ and effective R&D level $\ddot{\omega}_i$, with the same fixed amount of production inputs than would a firm producing innovation and imitation. It becomes clear that joint production entails a loss, so diseconomies of scope in R&D activities are present in (3).

3. Results

In this section, we analyse how business conduct in a competitive setting may affect the choice of research approach under the assumption of scope diseconomies, and we explore how optimal R&D approaches and managerial resource allocation choices determine R&D appropriability and are affected by changes in exogenous spillovers. We establish the comparative-statics implications of our model.

We need a few considerations and definitions before stating the comparative-statics results of this section. Firms have incentives to manage the flows of information to and from competitors. The ability to protect proprietary technological knowledge from leaking to other firms depends on the firmôs innovation activities such as the choice of research approach, and the appropriability conditions in the industry. Legal protection is assumed to be an industry variable, rather than a firm-specific characteristic. Through their research approaches, firms are able to affect their appropriation capabilities. We only use strategic protection through the choice of (a narrower) research approach as a firm-level variable. The strategic choice variable R&D approach denotes generality of a firmôs R&D agenda. The larger (smaller)θ_i, the more general (specific) is the R&D approach pursued by firm ï. Some models of Industrial Organization suggest that firms attempt to manage the external information flows, trying to

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